JC00 Rec'd PCT/PTO 03 AUG 2001

FORM PTO-1390 (REV 10-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER: CU-2605 RJS

U.S. APPLICATION NO. (If known, see 37 CFR 1.5): 09/890698

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/AU00/00099	14 February 2000	12 February 1999

TITLE OF INVENTION
LASER ABLATION OF WAVEGUIDE STRUCTURES

APPLICANT(S) FOR DO/EO/US
John CANNING et al

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. [X] This is an express request to promptly begin national examination procedures (35 U.S.C. 371(f)).
4. [X] The US has been elected by the expiration of 19 months from the priority date (PCT Article 31).
5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [X] is attached hereto (required only if not communicated by the International Bureau).
   b. [ ] has been communicated by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
6. [ ] An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
7. [X] Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [ ] are attached hereto (required only if not communicated by the International Bureau).
   b. [ ] have been communicated by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [X] have not been made and will not be made.
8. [ ] An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. [ ] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. [ ] An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 16 below concern document(s) or information included:

11. [ ] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [X] A FIRST preliminary amendment. w/marked set of claims
    [ ] A SECOND or SUBSEQUENT preliminary amendment.
14. [X] A substitute specification.
15. [ ] A change of power of attorney and/or address letter.
16. [ ] Other items or information:

Express Mail Label No.:
EL698181751US

U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 09/890698	INTERNATIONAL APPLICATION NO. PCT/AU00/00099	ATTORNEY'S DOCKET NUMBER CU-2605 RJS

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	CALCULATIONS	PTO USE ONLY
17. [X] The following fees are submitted: **BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):** Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO .... **$1000.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO....... **$860.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO .... **$710.00** International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) .... **$690.00** International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$1000.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	21 - 20 =	1	X $18.00	$ 18.00	
Independent claims	2 - 3 =	0	X $80.00	$	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ $270.00	$	

TOTAL OF ABOVE CALCULATIONS =	$1018.00	
[ ] Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.	$	
SUBTOTAL =	$1018.00	
Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +	$	
TOTAL NATIONAL FEE =	$	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +	$	
TOTAL FEES ENCLOSED =	$1018.00	
	Amount to be refunded:	$
	charged:	$

a. [X] A check in the amount of $ 1018.00 to cover the above fees is enclosed.

b. [ ] Please charge my Deposit Account No. ________ in the amount of $________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [X] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 12-0400. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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August 3, 2001

SIGNATURE:

Richard J. Streit
NAME

25765
REGISTRATION NUMBER

DOCKET: CU-2605

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

APPLICANT: John CANNING et al)
)
TITLE: LASER ABLATION OF WAVEGUIDE STRUCTURES)
)
COMPLETION OF PCT/AU00/00099 filed 14 February 2000)

The Commissioner for Patents (DO/EO/US)
Box PCT
Washington, D.C. 20231

PRELIMINARY AMENDMENT

Dear Sir:

Please amend the application being filed herewith under 35 USC 371.

IN THE CLAIMS:

Please cancel claims 1-21 from the PCT application as published as well as claims 1-21 from the claims attached to the International Preliminary Examination Report and substitute the clean version of claims 1-21 as attached to the substitute specification. A marked version of claim pages 10-11 from the International Preliminary Examination Report is also attached herewith indicating the changes made therein.

REMARKS

The aforesaid claims are based on the claims as filed in response to the Written Opinion in the PCT international application, with amendments to place the same in better condition for examination under U.S. rules of practice.

A substitute specification is enclosed and is based on the following materials:

- Page 1 as filed in the PCT international application
- Pages 2-3 as attached to the International Preliminary Examination Report
- Pages 4-9 as filed in the PCT international application
- Pages 10-11 of the amended claims as referenced above

- Page 12 of the abstract as filed in the PCT international application
- 6 sheets of drawings as filed in the PCT international application

Respectfully submitted,

August 3, 2001
Date

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We Claim:

1. A method of processing an optical device incorporating a waveguide, the method comprising the step of:

- utilizing a laser to heat and thereby ablate a surface of the device so as to induce a stress in said optical device and thereby alter an optical characteristic of the waveguide, wherein the power density of the laser is selected to effect surface ablation.

2. A method as claimed in claim 1 wherein the laser comprises a carbon dioxide laser source.

3. A method as claimed in ~~any one of the preceding claims~~ claim 1, wherein the method is utilized to alter the birefringent properties of the waveguide.

4. A method as claimed in claim 3 wherein the TM and TE birefringent modes are substantially aligned by the method.

5. A method as claimed in ~~any one of the preceding claims~~ claim 1, further comprising the step of masking the surface with a thermally conductive material having an aperture defined to minimise exposure of the device to the laser.

6. A method as claimed in ~~any one of the preceding claims~~ claim 1 wherein the device comprises a sensor.

7. A method as claimed in ~~any one of the preceding claims~~ claim 1, further comprising the step of:

- depositing a material layer on the surface.

8. A method as claimed in claim 7, wherein the step of depositing the material layer comprises depositing the material layer on portions of the surface affected by the ablation.

9. A method as claimed in ~~any one of the preceding claims~~ claim 1, further comprising the step of:

- mounting a further component in a groove formed in the surface as a result of the ablation.

10. A method as claimed in claim 7 ~~or 8~~, wherein the material layer is provided as an electrode for

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electrically contacting the device.

11. A method as claimed in claim 9, wherein the further component comprises a modulator for modulating a characteristic of the device.

12. A method as claimed in ~~any one of the preceding claims~~ claim 1, wherein the step of utilising the laser to heat the surface is conducted at different locations of the device so as to form an optical structure.

13. A method as claimed in claim 12, wherein the optical structure comprises a grating structure.

14. A method as claimed in claim~~s~~ 12 ~~or 13~~, wherein the optical structure comprises a polarization filter.

15. A method as claimed in ~~any one of the preceding claims~~ claim 1, wherein the method is used to diminish UV induced changes present in the waveguide.

16. A method as claimed in ~~any one of the preceding claims~~ claim 1, wherein the device comprises an optical fibre.

17. A method as claimed in ~~any one of the preceding claims~~ claim 1, wherein the method is utilized to mark the device by way of the ablation.

18. A method as claimed in ~~any one of the preceding claims,~~ claim 1, wherein the laser comprises a semiconductor laser operating at a wavelength of more than about 1.8 micro metre.

19. A method as claimed in claim 18, wherein the surface of the device comprises SiO_2.

20. A method as claimed in ~~nay one of the preceding claims,~~ claim 1, wherein the method further comprises the step of providing an absorber material to facilitate the heating of the surface of the device.

21. A device incorporating a waveguide, wherein the waveguide has been processed utilizing a laser to heat and thereby ablate a surface of the device so as to induce a stress in said device and thereby alter an optical characteristic of the waveguide, wherein the power density of the laser is selected to effect ablation.

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SUBSTITUTE SPECIFICATION

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8/3/01

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6/PRTS

LASER ABLATION OF WAVEGUIDE STRUCTURES

Field of the Invention

The present invention relates broadly to laser ablation (or alternatively sometimes referred to as laser etching, hereinafter referred to as ablation) processing of waveguide structures.

Background of the Invention

During the construction of optical waveguide devices, it is common that changes associated with a particular construction step occur which may affect the operational characteristics of the devices. For example, optical devices are often constructed utilizing an adaptation of semiconductor fabrication techniques and can commonly include a number of layers constructed on a silicon substrate. As a result of differential thermal expansion coefficients of the materials, various compressive stresses are induced during normal operating conditions. These stresses can have the effect of changing the operational characteristics of any device formed on the substrate. In particular, the compressive stresses can often give rise to anisotropic birefringent properties in optical waveguides which can substantially effect their operation.

Interim solutions suggested have included techniques such as employing complex hybrid technologies where bulk polarizing elements are slotted into an optical chip and set to compensate for birefringence, or providing time consuming chemical etching steps for etching strain relieving grooves on either side of a waveguide. Treatment via a UV laser to create damage at the substrate which leads to compensating stresses has also been suggested, however, the utilization of UV laser treatment has significant problems in that the lasers are expensive and can be unreliable in a manufacturing environment. They typically require constant skilled maintenance.

Summary of the Invention

The present invention provides a method of

processing an optical device incorporating a waveguide, the method comprising the step of utilizing a laser to heat and thereby ablate a surface of the device so as to induce a stress in said optical device and thereby alter an optical characteristic of the waveguide, wherein the power density of the laser is selected to effect surface ablation.

The laser may comprise a carbon dioxide laser source.

The method may be utilized to alter the birefringent properties of the waveguide, e.g. the TM and TE birefringent modes may be substantially aligned.

The method may further comprise the step of masking the surface with a thermally conductive material having an aperture defined therein to limit exposure of the device to the laser.

The device may comprise a sensor.

The method may further comprise the step of depositing a material layer on the surface. Accordingly, the method itself may be utilised to form the device. The device may eg. comprise a semiconductor device or a SiO_2/Si planar waveguide device.

Step of depositing the material layer may comprise depositing the material layer on portions of the surface affected by the ablation.

The material layer may be provided as an electrode for electrically contacting the device.

The method may further comprise the step of mounting a further component in a groove formed in the surface as a result of the ablation. The further component may comprise a modulator for modulating a characteristic of the device.

The method may be conducted at different locations of the device so as to form an optical structure. The optical structure may comprise a grating structure. The optical structure may comprise a polarisation filter.

The method may be used to diminish UV induced changes present in the waveguide.

The device may comprise an optical fibre.

The method may be utilised to mark the device by way of the ablation.

The laser may comprise a semiconductor laser operating at a wavelength of more than about 1.8 micro metre. This wavelength range may be preferable where the surface of the device comprises SiO_2.

The method may further comprise the step of providing an absorber material to facilitate the heating of the surface of the device.

The invention may alternatively be defined as providing an device incorporating a waveguide, wherein the device has been processed utilising a laser to heat and thereby ablate a surface of the device so as to induce a stress in said device and thereby alter an optical characteristic of the waveguide, wherein the power density of the laser is selected to effect surface ablation.

Brief Description of the Drawings

Notwithstanding any other forms which may fall within the scope of the present invention, preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 illustrates schematically the operation of the method of the preferred embodiment;

Fig. 2 illustrates the ablation of a wafer surface;

Fig. 3 illustrates the change and effective index in an experiment utilizing the preferred embodiment;

Fig. 4 illustrates a further change in the effective index of an experiment utilizing the preferred embodiment;

Fig. 5 illustrates the initial profile of a Mach-Zehnder (MZ) interferometer prior to application of preferred embodiment showing both the TM and TE modes;

Fig. 6 illustrates the spectral response for TE and TM modes of a MZ interferometer after application of the preferred embodiment for the device of Fig. 6;

Fig. 7 illustrates an alternative form of processing a wafer;

Fig. 8 illustrates the process of ablation around a core of a waveguide;

Fig. 9 illustrates the utilization of ablation in changing the device characteristics of a waveguide;

Fig. 10 illustrates the utilization of ablation in conjunction with deposition of further layers on a wafer; and

Fig. 11 illustrates the construction of a long period lossy grating.

Description of Preferred and Other Embodiments

In the preferred embodiment, an inexpensive and relatively compact CO_2 laser device is utilized to provide mid infrared laser processing of a waveguide structure so as to obtain both birefringence compensation and tuning of optical components. The processing set up is illustrated schematically in Fig. 1 wherein a waveguide 3 is subjected to ablation utilizing a CO_2 laser 5. An example of the ablation processing is illustrated in Fig. 2 wherein a waveguide 6 having a internal core 7 is processed so as to include ablation channels 8, 9. In a first example, the CO_2 laser was used to enhance the device characteristics of an asymmetric Mach-Zehnder (MZ) interferometer fabricated utilizing hollow-cathode PECVD techniques.

The mid-IR radiation was used to thermally relax stresses at the core and substrate as well as affect a change in the refractive index. At sufficiently high temperatures, the core and cladding waveguide glasses can be softened, melted and vaporised. These ablation processes themselves can be used to generate faster relaxation than would otherwise be possible as well as provide a source of polarisation dependent loss for energy stripping within waveguides for functions such as optical attenuators, and for other more classical applications, including the laser ablation of stress-relieving grooves. Most heating was found to occur through non-radiative transfer of absorbed light into vibrational modes of the silica molecule.

For given exposures utilized in experiments, the substrate temperature was thought to be approximately the same as that induced at the surface. The laser was operated initially with unfocussed 10W of CW power (~ 140W/cm^2). When the laser was later focused, temperatures readily exceeding the melting point of silica were achieved resulting in laser vaporisation and ablation.

Since the asymmetric MZ spectral response is characteristic of the interferometer established between the input and output couplers, birefringence compensation, as measured by matched TE and TM spectra (the TM identified to have a higher effective index by writing a weak Bragg grating in a straight waveguide manufactured on the same wafer), can be achieved between the two couplers. From an experimental point of view, if true birefringence reduction in this region is demonstrated, the change in TE and TM notch wavelength due to an increase in effective index must be such that they converge when processing the longer arm, and diverge when processing the shorter arm. The reverse is the case for a decrease in refractive index. Otherwise, spectral compensation of polarisation is possible within a MZ whilst actually worsening the intrinsic polarisation dispersion. When convergence is achieved, then the feasibility of polarisation compensation can be established which is generally applicable to other optical components and straight waveguides as well as the asymmetric MZ device chosen here.

In the experiments to determine the parameters of operation, optical spectra were taken, of the MZ device using a broadband erbium-doped fibre amplifier (EDFA) and a spectrum analyser with a resolution of 0.05nm, limiting the birefringence splitting which can be measured to ~1×10^{-5}.

In initial experiments, the longer arm of a MZ device (12μm SiO_2 cladding and buffer layers, 4x5 μm GeO_2-doped core, $\Delta n \sim 0.01$) was processed for testing and confirmation of the concept. Measurements were taken at intervals after briefly halting the exposure at fixed times

since the fibre coupling was increasingly affected by longer exposures. It was noted that both TE and TM shifted to longer wavelengths indicating an increase in refractive index. The TE effective index eventually increased more rapidly such that the splitting was reduced as shown in Fig. 4 which shows the change in wavelength splitting between TE and TM eigenstate with exposure to unfocussed light. Initially, however, as shown in Fig. 3, an increase in the splitting observed. We believe is related to an initial increase in compressive stress and subsequent compaction of the core glass. The magnitude of reduction is sufficient to allow compensation of birefringence in most planar silica-on-silicon devices where the splitting is much lower than the device chosen here. Further, this value is unsaturated.

The power density of the CO_2 laser was then increased to -1.3kW/cm^2 by focussing to a 100μm spot size such that we exceed the threshold necessary for vaporisation for an exposure of less then 0.2s. Ablation was confirmed under an optical microscope after gently cleaving through one damage region of the surface. By controlling the duration of the exposure it was possible to control the depth to which material is removed. The spectral responses when exposing the longer arm were found to shift to shorter wavelengths indicating a decrease in refractive index. However, the TM state was found to decrease more rapidly resulting in a large drop in the birefringence splitting. The decrease in refractive index and the localised ablation indicates that in this case dilation and stress compensation or relaxation at the core are the main factors responsible for the reduction in birefringence. Fibre coupling is significantly more stable (an important advantage for *in-situ* monitoring) and the process is clearly more efficient than thermal annealing of the material. This will affect the effective propagation constants for each polarisation state as well as introduce some polarisation dependent loss. The result is that this

can be used to achieve balancing of the optical energy for each eigenstate and hence result in a matched and improved spectral response of the device. Fig. 4 shows the change in effective index as a function of shots fired in the same region and shows the convergence of birefringence when exposing the longer arm. It was noted that subsequent successive shots on the same region did not contribute any further. Indeed a small reversal was observed. Exposing the shorter arm showed spectral divergence, as expected if polarisation compensation has been achieved.

The spectral response for a second device utilized in experiments (essentially a polarisation splitter) prior to irradiation is shown in Fig. 5. The poor fringe contrast and the difference between TE and TM responses indicates that the input coupler is polarisation sensitive and that different amounts of light are split for each eigenstate. As a result, the intensity of light in each arm is not equal leading to poor fringe contrast upon recombination at the output coupler, particularly in this case of the TE state. The polarisation sensitivity between couplers is very difficult to eliminate completely in silica-on-silicon systems where strain is not readily removed. Fig. 6 illustrates the end results on the device once the process of irradiation ablation was optimised. An improvement is fringe contrast to 20dB for both TE and TM states was achieved after five shots along the longer arm (power density -10kW/cm^2). The total increase in loss necessary to balance the polarisation states in this particular device was -0.12 dB for TM and -1.2dB for TE.

A number of further modifications and applications of the aforementioned technique are possible. Firstly, the utilisation of the CO_2 laser can be refined as illustrated in Fig. 7 by utilizing a metal plate 20 containing a slot 21 with the metal plate acting as a heat sink so as to extract heat from the laser beam 22 outside specific locations. In this manner, more refined processing 23 of the waveguide can be achieved.

Secondly, the ablation of the waveguide can also be extended, as shown in Fig. 8, to the area surrounding the core 25. This can be utilized to effect the operation of the core and the overall device. For example, in Fig. 9, there is illustrated the utilization of ablation to form a refined surface 30 which can be utilized to provide for more accurate sensing by the core 31. Further, the ablation of the surface can be utilized in the construction of complex semi-conductor devices having predetermined operational characteristics. For example, in Fig. 10, there is illustrated the example of deposition of a subsequent layer 33 which can comprise zinc oxide, $BiTO_3$ or the like so as to provide for a functional semiconductor device.

A further example refinement is illustrated in Fig. 11 where a series of ablations 40-42 are written at regular intervals along a core 43 so as to provide for a long period "loss" grating structure.

Other applications can include modification of polarization controllers and attenuators etc.

The aforementioned laser process has a number of other uses. In particular, it can be used to provide for accelerated aging of components by means of CO_2 thermal heating of optical devices such as UV processed gratings formed on a planar waveguide. The accelerated aging can provide for improved operational characteristics and can include precise localised aging of components. Further, the thermal annealing can be utilized to anneal out the UV processing of portions of a previously processed waveguide. This can be taken to the extent of almost totally annealing out the UV processing effect.

Further, the above processing steps are also directly applicable to fibre devices.

It would be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of

the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A method of processing an optical device incorporating a waveguide, the method comprising the step of:

utilizing a laser to heat and thereby ablate a surface of the device so as to induce a stress in said optical device and thereby alter an optical characteristic of the waveguide, wherein the power density of the laser is selected to effect surface ablation.

2. A method as claimed in claim 1, wherein the laser comprises a carbon dioxide laser source.

3. A method as claimed in claim 1, wherein the method is utilized to alter the birefringent properties of the waveguide.

4. A method as claimed in claim 3, wherein the TM and TE birefringent modes are substantially aligned by the method.

5. A method as claimed in claim 1, further comprising the step of masking the surface with a thermally conductive material having an aperture defined to minimize exposure of the device to the laser.

6. A method as claimed in claim 1, wherein the device comprises a sensor.

7. A method as claimed in claim 1, further comprising the step of depositing a material layer on the surface.

8. A method as claimed in claim 7, wherein the step of depositing the material layer comprises depositing the material layer on portions of the surface affected by the ablation.

9 A method as claimed in claim 1, further comprising the step of mounting a further component in a groove formed in the surface as a result of the ablation

10. A method as claimed in claim 7, wherein the material layer is provided as an electrode for electrically contacting the device.

11. A method as claimed in claim 9, wherein the further component comprises a modulator for modulating a characteristic of the device.

12. A method as claimed in claim 1, wherein the step of utilizing the laser to heat the surface is conducted at different locations of the device so as to form an optical structure.

13. A method as claimed in claim 12, wherein the optical structure comprises a grating structure.

14. A method as claimed in claim 12, wherein the optical structure comprises a polarization filter.

15. A method as claimed in claim 1, wherein the method is used to diminish UV induced changes present in the waveguide.

16. A method as claimed in claim 1, wherein the device comprises an optical fibre.

17 A method as claimed in claim 1, wherein the method is utilized to mark the device by way of the ablation.

18. A method as claimed in claim 1, wherein the laser comprises a semiconductor laser operating at a wavelength of more than about 1.8 micro metre.

19. A method as claimed in claim 18, wherein the surface of the device comprises SiO_2.

20. A method as claimed in claim 1, wherein the method further comprises the step of providing an absorber material to facilitate the heating of the surface of the device.

21. A device incorporating a waveguide, wherein the waveguide has been processed utilizing a laser to heat and thereby ablate a surface of the device so as to induce a stress in said device and thereby alter an optical characteristic of the waveguide, wherein the power density of the laser is selected to effect ablation.

ABSTRACT

A method of processing an optical device incorporating a waveguide, the method comprising the step of utilizing a laser to heat a surface of the device to alter an optical characteristic of the waveguide, wherein the power density of the laser is selected to effect ablation.

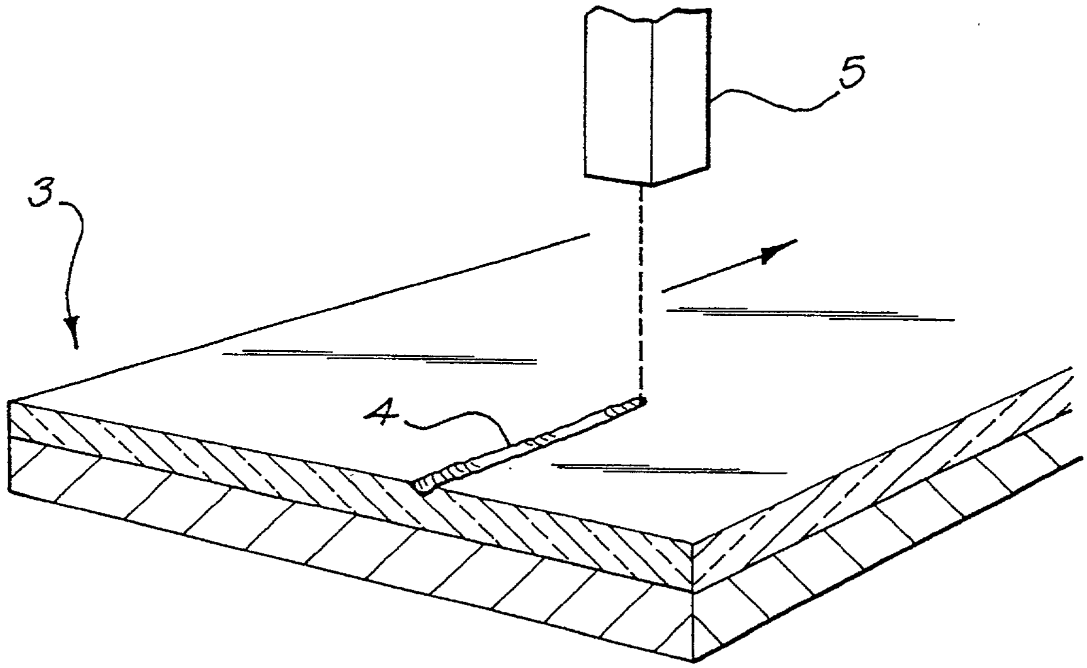


FIG. 1

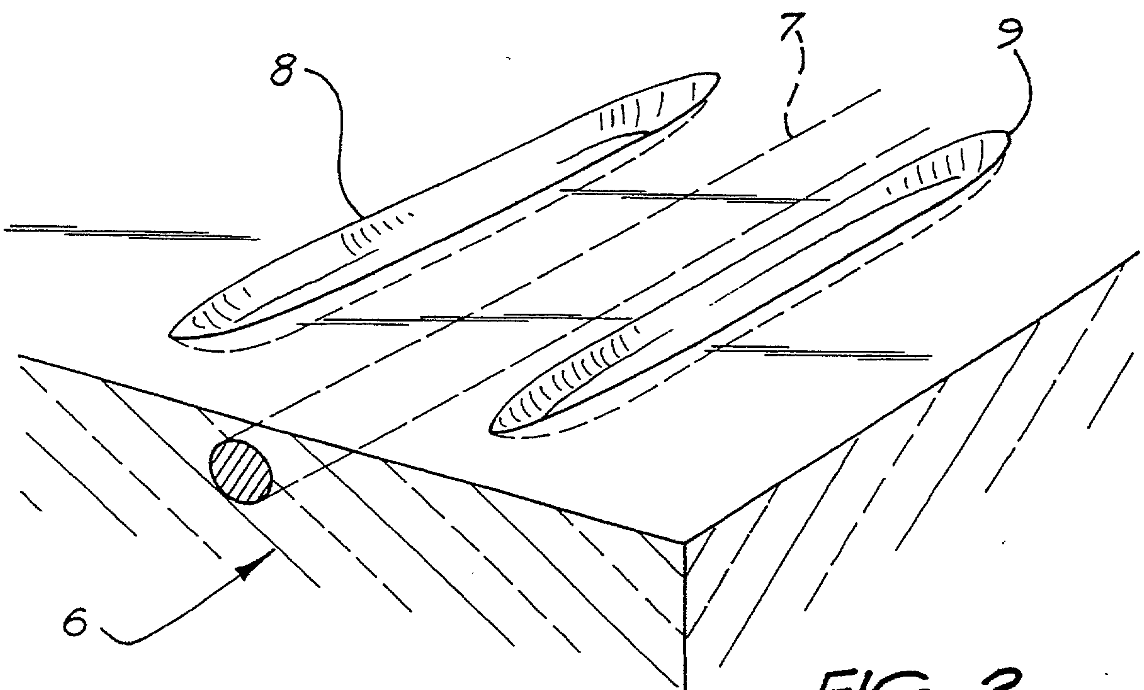
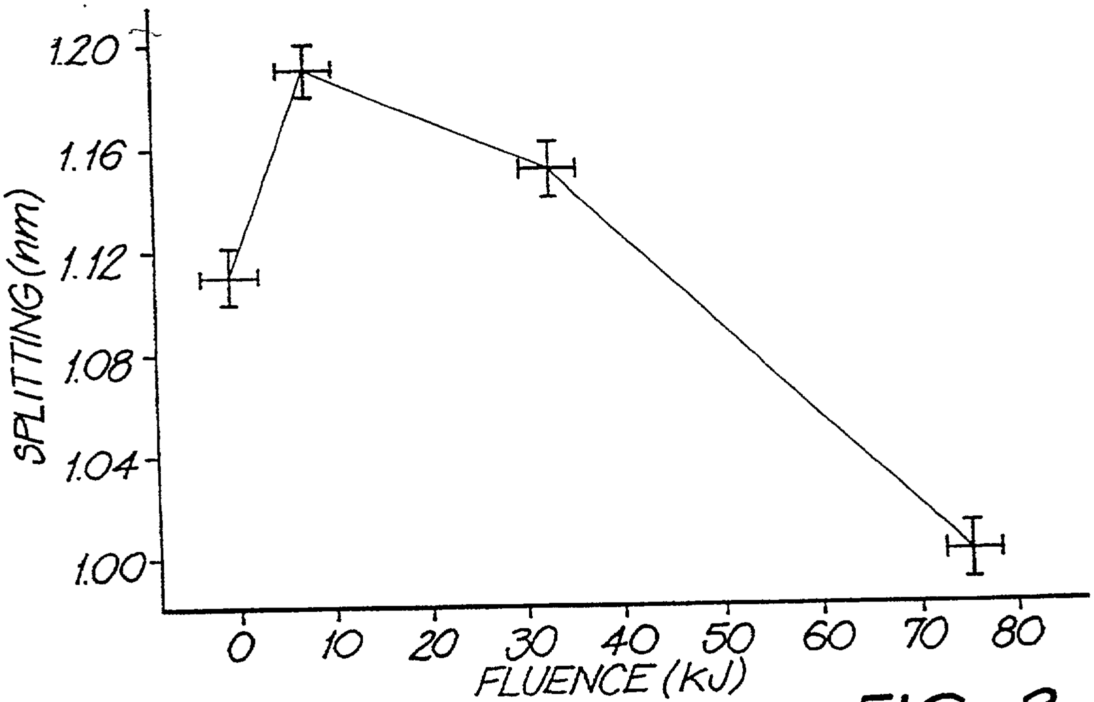


FIG. 2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1.16
1.12
1.08
1.04
1.00
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10
20
30
40
50
60
70
80
FLUENCE (kJ)

FIG. 3

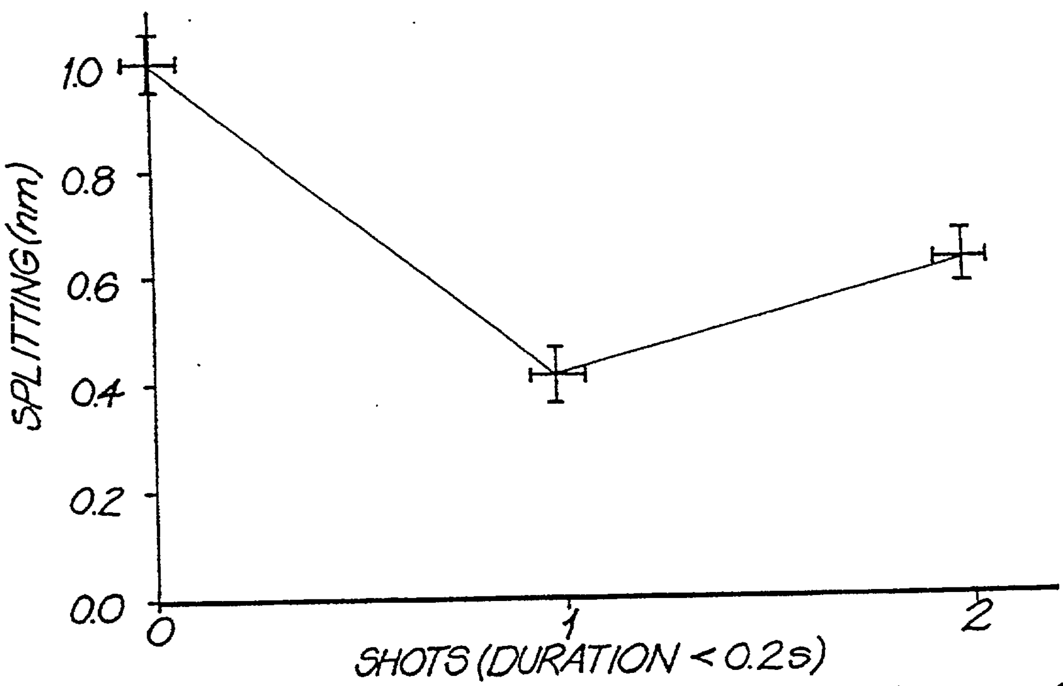
1.0
0.8
0.6
0.4
0.2
0.0
SPLITTING (nm)
0
1
2
SHOTS (DURATION < 0.2s)

FIG. 4

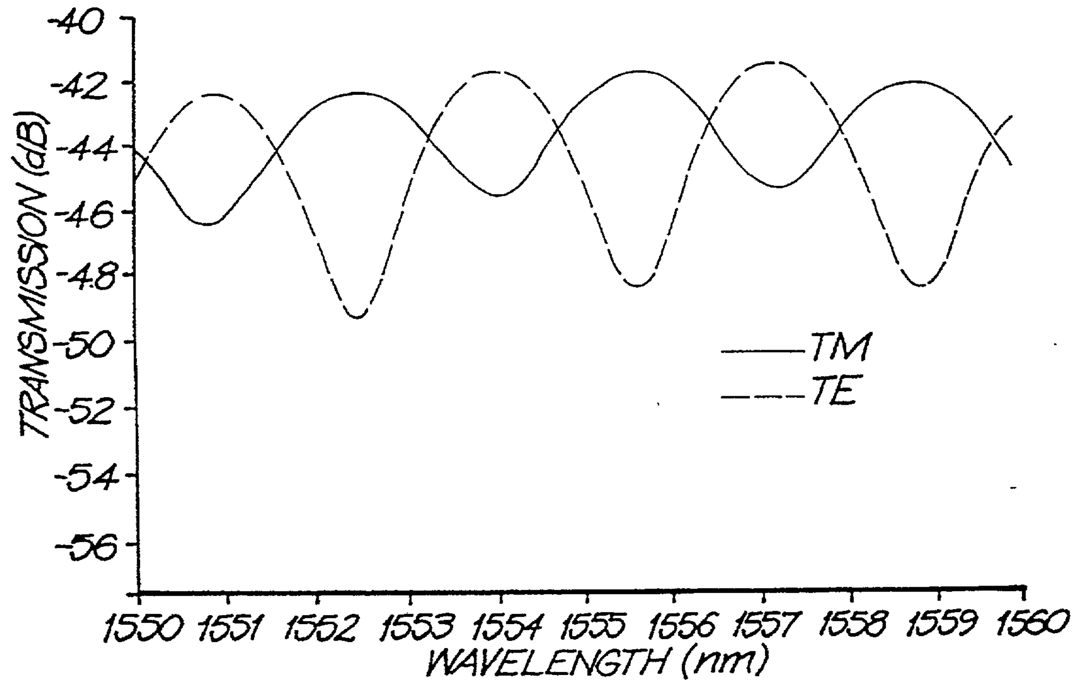
-40
-42
-44
-46
-48
-50
-52
-54
-56
TRANSMISSION (dB)
TM
TE
1550 1551 1552 1553 1554 1555 1556 1557 1558 1559 1560
WAVELENGTH (nm)

FIG. 5

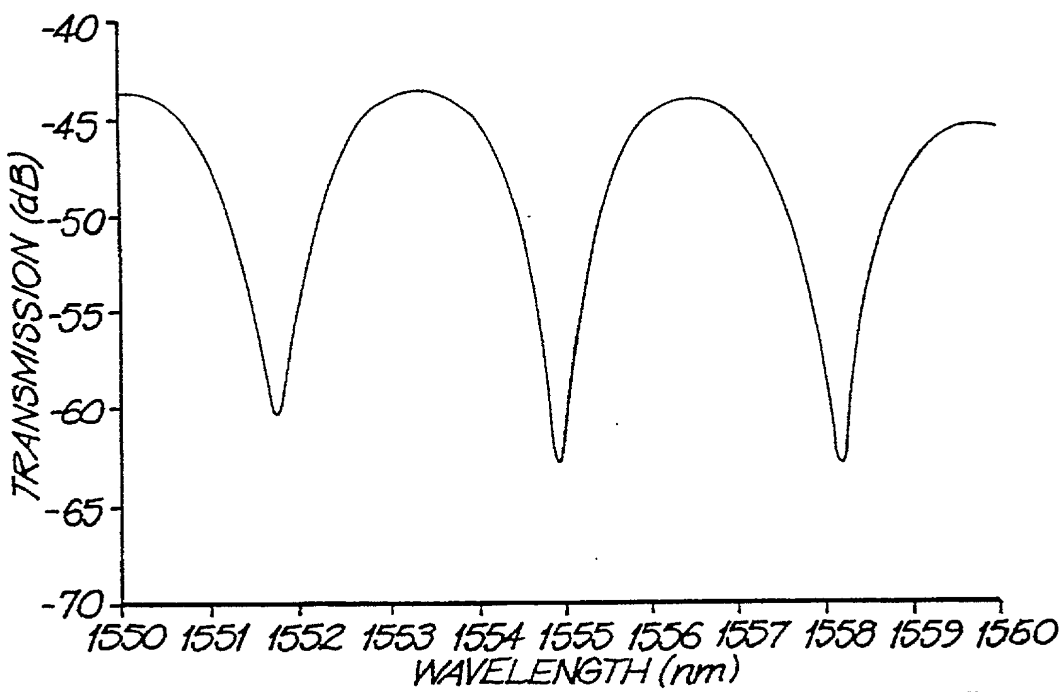
-40
-45
-50
-55
-60
-65
-70
TRANSMISSION (dB)
1550 1551 1552 1553 1554 1555 1556 1557 1558 1559 1560
WAVELENGTH (nm)

FIG. 6

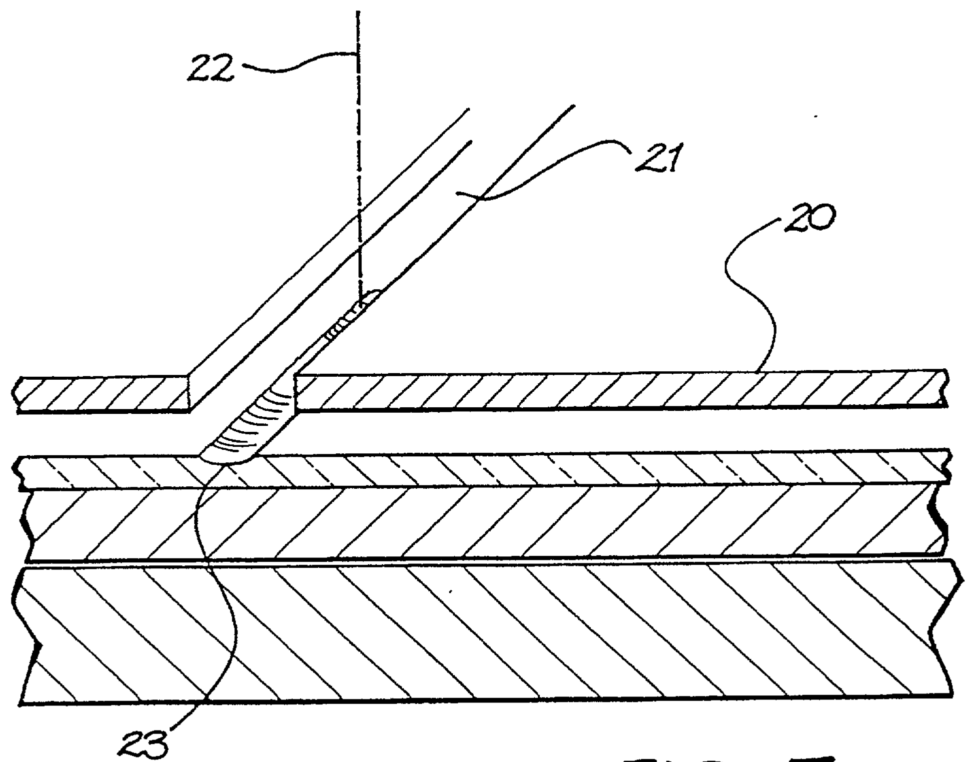

FIG. 7

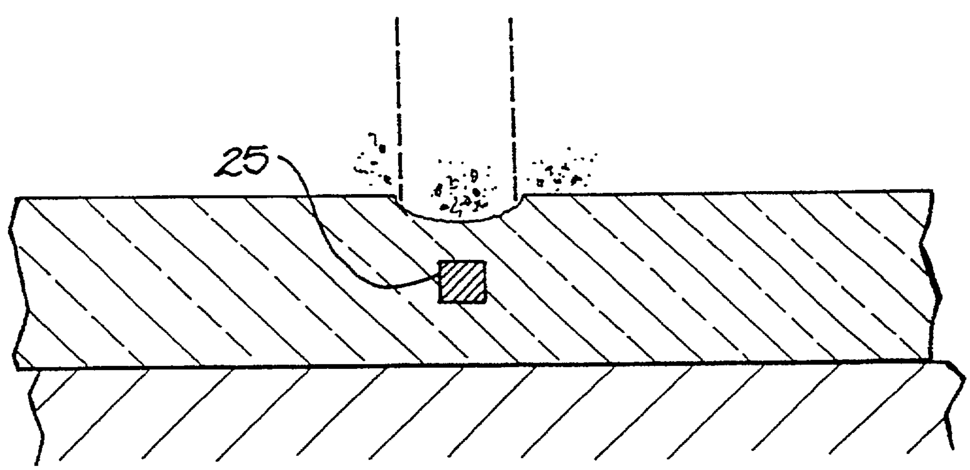

FIG. 8

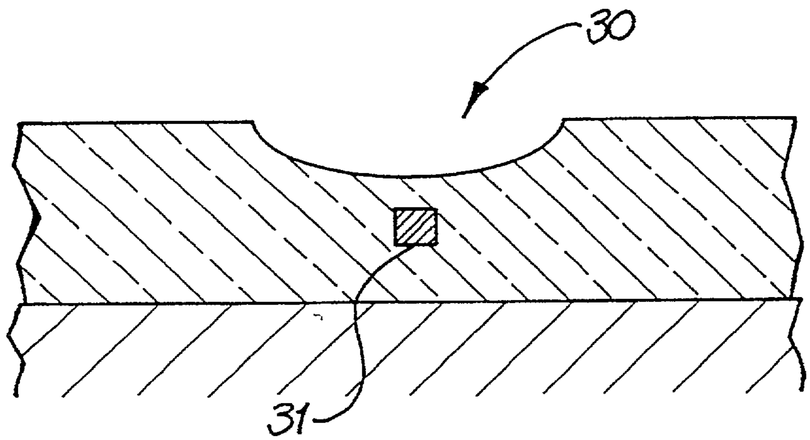

FIG. 9

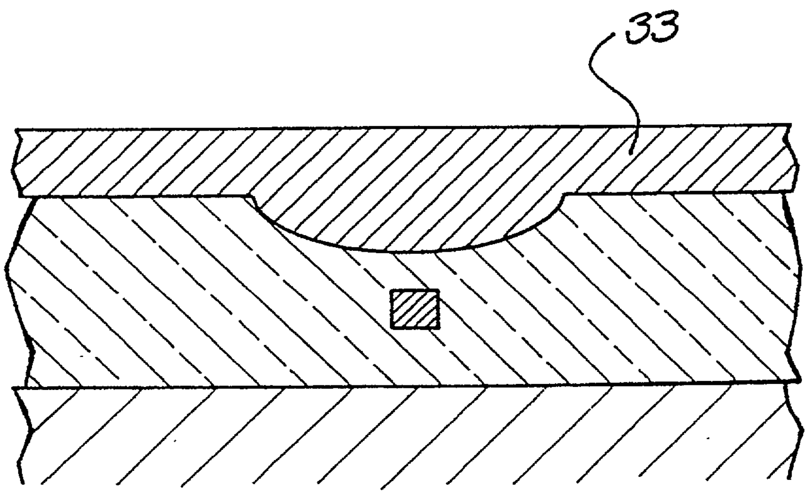

FIG. 10

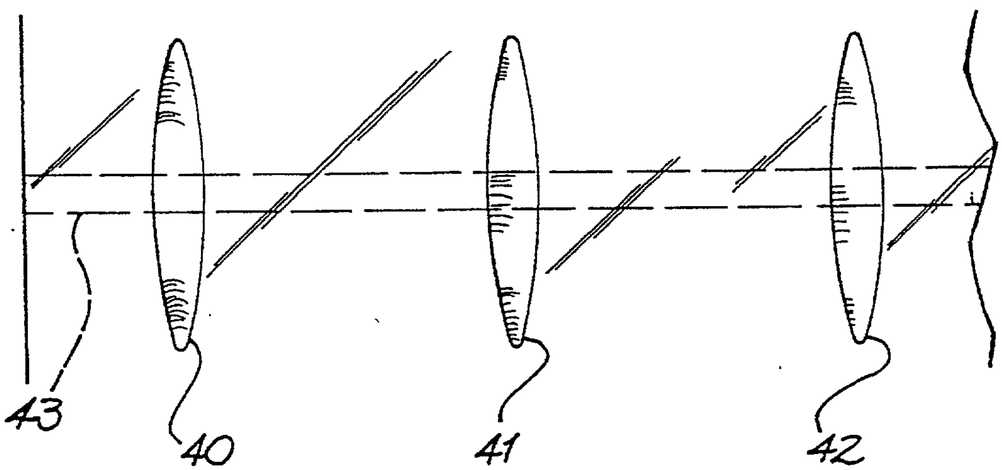

FIG. 11

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PCT/AU00/00099

LASER ABLATION OF WAVEGUIDE STRUCTURES

Field of the Invention

The present invention relates broadly to laser ablation (or alternatively sometimes referred to as laser etching, hereinafter referred to as ablation) processing of waveguide structures.

Background of the Invention

During the construction of optical waveguide devices, it is common that changes associated with a particular construction step occur which may affect the operational characteristics of the devices. For example, optical devices are often constructed utilizing an adaptation of semiconductor fabrication techniques and can commonly include a number of layers constructed on a silicon substrate. As a result of differential thermal expansion coefficients of the materials, various compressive stresses are induced during normal operating conditions. These stresses can have the effect of changing the operational characteristics of any device formed on the substrate. In particular, the compressive stresses can often give rise to anisotropic birefringent properties in optical waveguides which can substantially effect their operation.

Interim solutions suggested have included techniques such as employing complex hybrid technologies where bulk polarizing elements are slotted into an optical chip and set to compensate for birefringence, or providing time consuming chemical etching steps for etching strain relieving grooves on either side of a waveguide. Treatment via a UV laser to create damage at the substrate which leads to compensating stresses has also been suggested, however, the utilization of UV laser treatment has significant problems in that the lasers are expensive and can be unreliable in a manufacturing environment. They typically require constant skilled maintenance.

Summary of the Invention

The present invention provides a method of

processing an optical device incorporating a waveguide, the method comprising the step of utilizing a laser to heat and thereby ablate a surface of the device so as to induce a stress in said optical device and thereby alter an optical characteristic of the waveguide, wherein the power density of the laser is selected to effect surface ablation.

The laser may comprise a carbon dioxide laser source.

The method may be utilized to alter the birefringent properties of the waveguide, e.g. the TM and TE birefringent modes may be substantially aligned.

The method may further comprise the step of masking the surface with a thermally conductive material having an aperture defined therein to limit exposure of the device to the laser.

The device may comprise a sensor.

The method may further comprise the step of depositing a material layer on the surface. Accordingly, the method itself may be utilised to form the device. The device may eg. comprise a semiconductor device or a SiO_2/Si planar waveguide device.

Step of depositing the material layer may comprise depositing the material layer on portions of the surface affected by the ablation.

The material layer may be provided as an electrode for electrically contacting the device.

The method may further comprise the step of mounting a further component in a groove formed in the surface as a result of the ablation. The further component may comprise a modulator for modulating a characteristic of the device.

The method may be conducted at different locations of the device so as to form an optical structure. The optical structure may comprise a grating structure. The optical structure may comprise a polarisation filter.

The method may be used to diminish UV induced changes present in the waveguide.

The device may comprise an optical fibre.

The method may be utilised to mark the device by way of the ablation.

The laser may comprise a semiconductor laser operating at a wavelength of more than about 1.8 micro metre. This wavelength range may be preferable where the surface of the device comprises SiO_2.

The method may further comprise the step of providing an absorber material to facilitate the heating of the surface of the device.

The invention may alternatively be defined as providing an device incorporating a waveguide, wherein the device has been processed utilising a laser to heat and thereby ablate a surface of the device so as to induce a stress in said device and thereby alter an optical characteristic of the waveguide, wherein the power density of the laser is selected to effect surface ablation.

Brief Description of the Drawings

Notwithstanding any other forms which may fall within the scope of the present invention, preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 illustrates schematically the operation of the method of the preferred embodiment;

Fig. 2 illustrates the ablation of a wafer surface;

Fig. 3 illustrates the change and effective index in an experiment utilizing the preferred embodiment;

Fig. 4 illustrates a further change in the effective index of an experiment utilizing the preferred embodiment;

Fig. 5 illustrates the initial profile of a Mach-Zehnder (MZ) interferometer prior to application of preferred embodiment showing both the TM and TE modes;

Fig. 6 illustrates the spectral response for TE and TM modes of a MZ interferometer after application of the preferred embodiment for the device of Fig. 6;

Fig. 7 illustrates an alternative form of processing a wafer;

Fig. 8 illustrates the process of ablation around a core of a waveguide;

Fig. 9 illustrates the utilization of ablation in changing the device characteristics of a waveguide;

Fig. 10 illustrates the utilization of ablation in conjunction with deposition of further layers on a wafer; and

Fig. 11 illustrates the construction of a long period lossy grating.

Description of Preferred and Other Embodiments

In the preferred embodiment, an inexpensive and relatively compact CO_2 laser device is utilized to provide mid infrared laser processing of a waveguide structure so as to obtain both birefringence compensation and tuning of optical components. The processing set up is illustrated schematically in Fig. 1 wherein a waveguide 3 is subjected to ablation utilizing a CO_2 laser 5. An example of the ablation processing is illustrated in Fig. 2 wherein a waveguide 6 having a internal core 7 is processed so as to include ablation channels 8, 9. In a first example, the CO_2 laser was used to enhance the device characteristics of an asymmetric Mach-Zehnder (MZ) interferometer fabricated utilizing hollow-cathode PECVD techniques.

The mid-IR radiation was used to thermally relax stresses at the core and substrate as well as affect a change in the refractive index. At sufficiently high temperatures, the core and cladding waveguide glasses can be softened, melted and vaporised. These ablation processes themselves can be used to generate faster relaxation than would otherwise be possible as well as provide a source of polarisation dependent loss for energy stripping within waveguides for functions such as optical attenuators, and for other more classical applications, including the laser ablation of stress-relieving grooves. Most heating was found to occur through non-radiative transfer of absorbed light into vibrational modes of the silica molecule.

For given exposures utilized in experiments, the substrate temperature was thought to be approximately the same as that induced at the surface. The laser was operated initially with unfocussed 10W of CW power (~ 140W/cm^2). When the laser was later focused, temperatures readily exceeding the melting point of silica were achieved resulting in laser vaporisation and ablation.

Since the asymmetric MZ spectral response is characteristic of the interferometer established between the input and output couplers, birefringence compensation, as measured by matched TE and TM spectra (the TM identified to have a higher effective index by writing a weak Bragg grating in a straight waveguide manufactured on the same wafer), can be achieved between the two couplers. From an experimental point of view, if true birefringence reduction in this region is demonstrated, the change in TE and TM notch wavelength due to an increase in effective index must be such that they converge when processing the longer arm, and diverge when processing the shorter arm. The reverse is the case for a decrease in refractive index. Otherwise, spectral compensation of polarisation is possible within a MZ whilst actually worsening the intrinsic polarisation dispersion. When convergence is achieved, then the feasibility of polarisation compensation can be established which is generally applicable to other optical components and straight waveguides as well as the asymmetric MZ device chosen here.

In the experiments to determine the parameters of operation, optical spectra were taken, of the MZ device using a broadband erbium-doped fibre amplifier (EDFA) and a spectrum analyser with a resolution of 0.05nm, limiting the birefringence splitting which can be measured to ~$1x10^{-5}$.

In initial experiments, the longer arm of a MZ device (12µm SiO_2 cladding and buffer layers, 4x5 µm GeO_2-doped core, Δn ~ 0.01) was processed for testing and confirmation of the concept. Measurements were taken at intervals after briefly halting the exposure at fixed times

since the fibre coupling was increasingly affected by longer exposures. It was noted that both TE and TM shifted to longer wavelengths indicating an increase in refractive index. The TE effective index eventually increased more rapidly such that the splitting was reduced as shown in Fig. 4 which shows the change in wavelength splitting between TE and TM eigenstate with exposure to unfocussed light. Initially, however, as shown in Fig. 3, an increase in the splitting observed. We believe is related to an initial increase in compressive stress and subsequent compaction of the core glass. The magnitude of reduction is sufficient to allow compensation of birefringence in most planar silica-on-silicon devices where the splitting is much lower than the device chosen here. Further, this value is unsaturated.

The power density of the CO_2 laser was then increased to -1.3kW/cm^2 by focussing to a 100μm spot size such that we exceed the threshold necessary for vaporisation for an exposure of less then 0.2s. Ablation was confirmed under an optical microscope after gently cleaving through one damage region of the surface. By controlling the duration of the exposure it was possible to control the depth to which material is removed. The spectral responses when exposing the longer arm were found to shift to shorter wavelengths indicating a decrease in refractive index. However, the TM state was found to decrease more rapidly resulting in a large drop in the birefringence splitting. The decrease in refractive index and the localised ablation indicates that in this case dilation and stress compensation or relaxation at the core are the main factors responsible for the reduction in birefringence. Fibre coupling is significantly more stable (an important advantage for *in-situ* monitoring) and the process is clearly more efficient than thermal annealing of the material. This will affect the effective propagation constants for each polarisation state as well as introduce some polarisation dependent loss. The result is that this

can be used to achieve balancing of the optical energy for each eigenstate and hence result in a matched and improved spectral response of the device. Fig. 4 shows the change in effective index as a function of shots fired in the same region and shows the convergence of birefringence when exposing the longer arm. It was noted that subsequent successive shots on the same region did not contribute any further. Indeed a small reversal was observed. Exposing the shorter arm showed spectral divergence, as expected if polarisation compensation has been achieved.

The spectral response for a second device utilized in experiments (essentially a polarisation splitter) prior to irradiation is shown in Fig. 5. The poor fringe contrast and the difference between TE and TM responses indicates that the input coupler is polarisation sensitive and that different amounts of light are split for each eigenstate. As a result, the intensity of light in each arm is not equal leading to poor fringe contrast upon recombination at the output coupler, particularly in this case of the TE state. The polarisation sensitivity between couplers is very difficult to eliminate completely in silica-on-silicon systems where strain is not readily removed. Fig. 6 illustrates the end results on the device once the process of irradiation ablation was optimised. An improvement is fringe contrast to 20dB for both TE and TM states was achieved after five shots along the longer arm (power density -10kW/cm^2). The total increase in loss necessary to balance the polarisation states in this particular device was -0.12 dB for TM and -1.2dB for TE.

A number of further modifications and applications of the aforementioned technique are possible. Firstly, the utilisation of the CO_2 laser can be refined as illustrated in Fig. 7 by utilizing a metal plate 20 containing a slot 21 with the metal plate acting as a heat sink so as to extract heat from the laser beam 22 outside specific locations. In this manner, more refined processing 23 of the waveguide can be achieved.

Secondly, the ablation of the waveguide can also be extended, as shown in Fig. 8, to the area surrounding the core 25. This can be utilized to effect the operation of the core and the overall device. For example, in Fig. 9, there is illustrated the utilization of ablation to form a refined surface 30 which can be utilized to provide for more accurate sensing by the core 31. Further, the ablation of the surface can be utilized in the construction of complex semi-conductor devices having predetermined operational characteristics. For example, in Fig. 10, there is illustrated the example of deposition of a subsequent layer 33 which can comprise zinc oxide, $BiTO_3$ or the like so as to provide for a functional semiconductor device.

A further example refinement is illustrated in Fig. 11 where a series of ablations 40-42 are written at regular intervals along a core 43 so as to provide for a long period "loss" grating structure.

Other applications can include modification of polarization controllers and attenuators etc.

The aforementioned laser process has a number of other uses. In particular, it can be used to provide for accelerated aging of components by means of CO_2 thermal heating of optical devices such as UV processed gratings formed on a planar waveguide. The accelerated aging can provide for improved operational characteristics and can include precise localised aging of components. Further, the thermal annealing can be utilized to anneal out the UV processing of portions of a previously processed waveguide. This can be taken to the extent of almost totally annealing out the UV processing effect.

Further, the above processing steps are also directly applicable to fibre devices.

It would be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of

the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

<u>We Claim</u>:

1. A method of processing an optical device incorporating a waveguide, the method comprising the step of:

- utilizing a laser to heat and thereby ablate a surface of the device so as to induce a stress in said optical device and thereby alter an optical characteristic of the waveguide, wherein the power density of the laser is selected to effect surface ablation.

2. A method as claimed in claim 1 wherein the laser comprises a carbon dioxide laser source.

3. A method as claimed in any one of the preceding claims wherein the method is utilized to alter the birefringent properties of the waveguide.

4. A method as claimed in claim 3 wherein the TM and TE birefringent modes are substantially aligned by the method.

5. A method as claimed in any one of the preceding claims further comprising the step of masking the surface with a thermally conductive material having an aperture defined to minimise exposure of the device to the laser.

6. A method as claimed in any one of the preceding claims wherein the device comprises a sensor.

7. A method as claimed in any one of the preceding claims further comprising the step of:

- depositing a material layer on the surface.

8. A method as claimed in claim 7, wherein the step of depositing the material layer comprises depositing the material layer on portions of the surface affected by the ablation.

9. A method as claimed in any one of the preceding claims further comprising the step of:

- mounting a further component in a groove formed in the surface as a result of the ablation.

10. A method as claimed in claim 7 or 8, wherein the material layer is provided as an electrode for

electrically contacting the device.

11. A method as claimed in claim 9, wherein the further component comprises a modulator for modulating a characteristic of the device.

12. A method as claimed in any one of the preceding claims wherein the step of utilising the laser to heat the surface is conducted at different locations of the device so as to form an optical structure.

13. A method as claimed in claim 12, wherein the optical structure comprises a grating structure.

14. A method as claimed in claims 12 or 13, wherein the optical structure comprises a polarisation filter.

15. A method as claimed in any one of the preceding claims wherein the method is used to diminish UV induced changes present in the waveguide.

16. A method as claimed in any one of the preceding claims wherein the device comprises an optical fibre.

17. A method as claimed in any one of the preceding claims wherein the method is utilised to mark the device by way of the ablation.

18. A method as claimed in any one of the preceding claims, wherein the laser comprises a semiconductor laser operating at a wavelength of more than about 1.8 micro metre.

19. A method as claimed in claim 18, wherein the surface of the device comprises SiO_2.

20. A method as claimed in nay one of the preceding claims, wherein the method further comprises the step of providing an absorber material to facilitate the heating of the surface of the device.

21. A device incorporating a waveguide, wherein the waveguide has been processed utilising a laser to heat and thereby ablate a surface of the device so as to induce a stress in said device and thereby alter an optical characteristic of the waveguide, wherein the power density of the laser is selected to effect ablation.

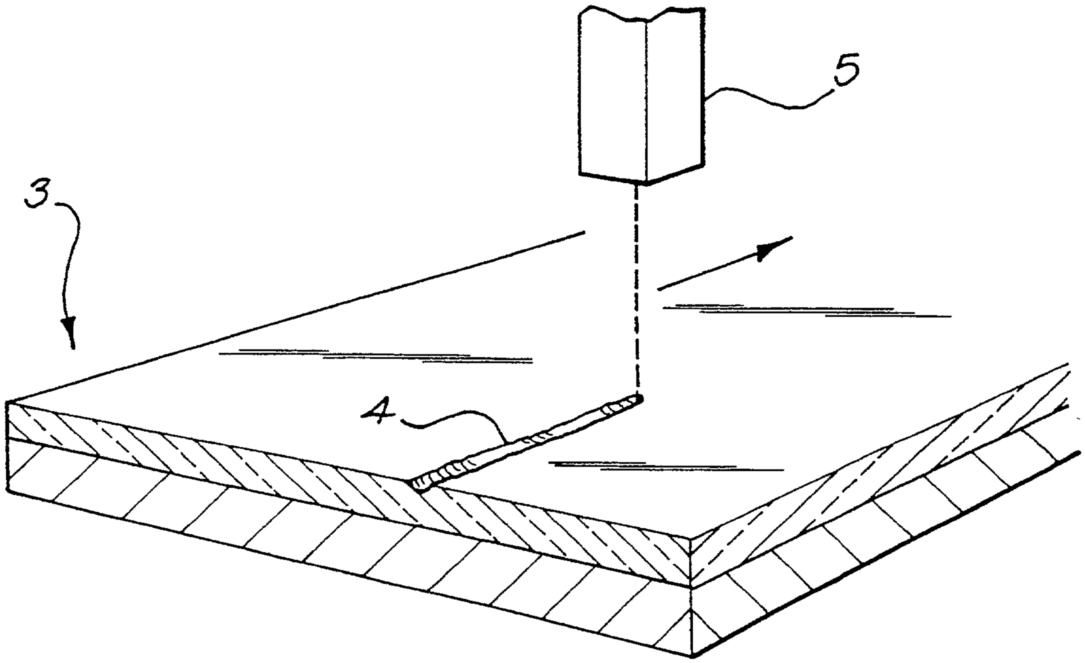

FIG. 1

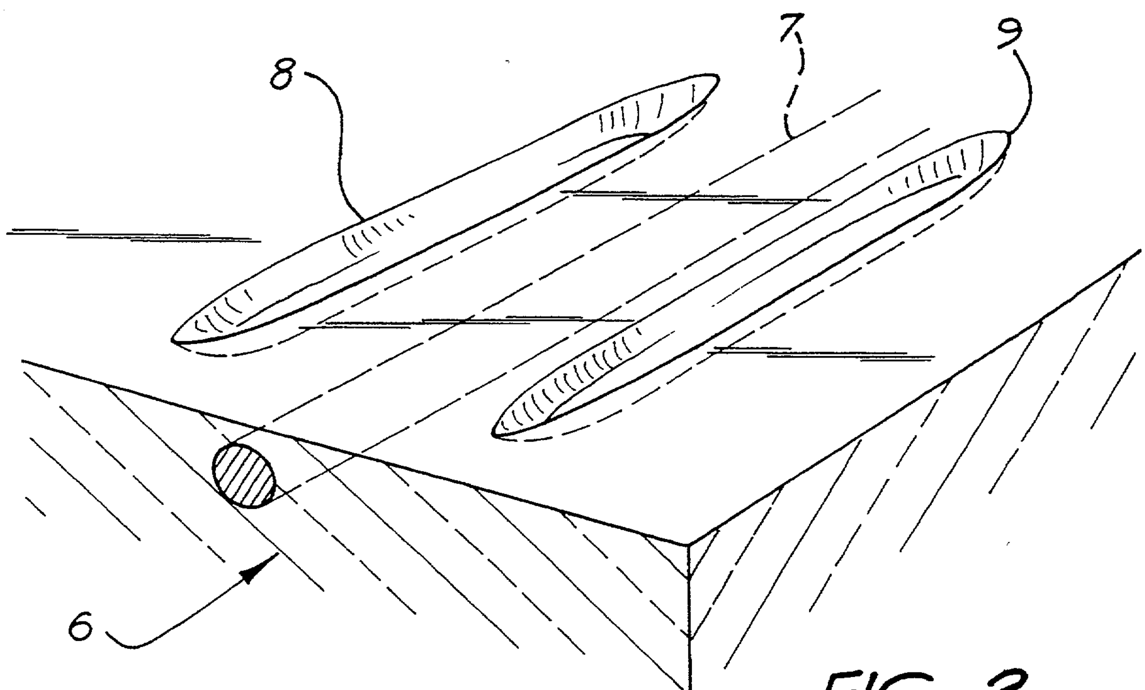

FIG. 2

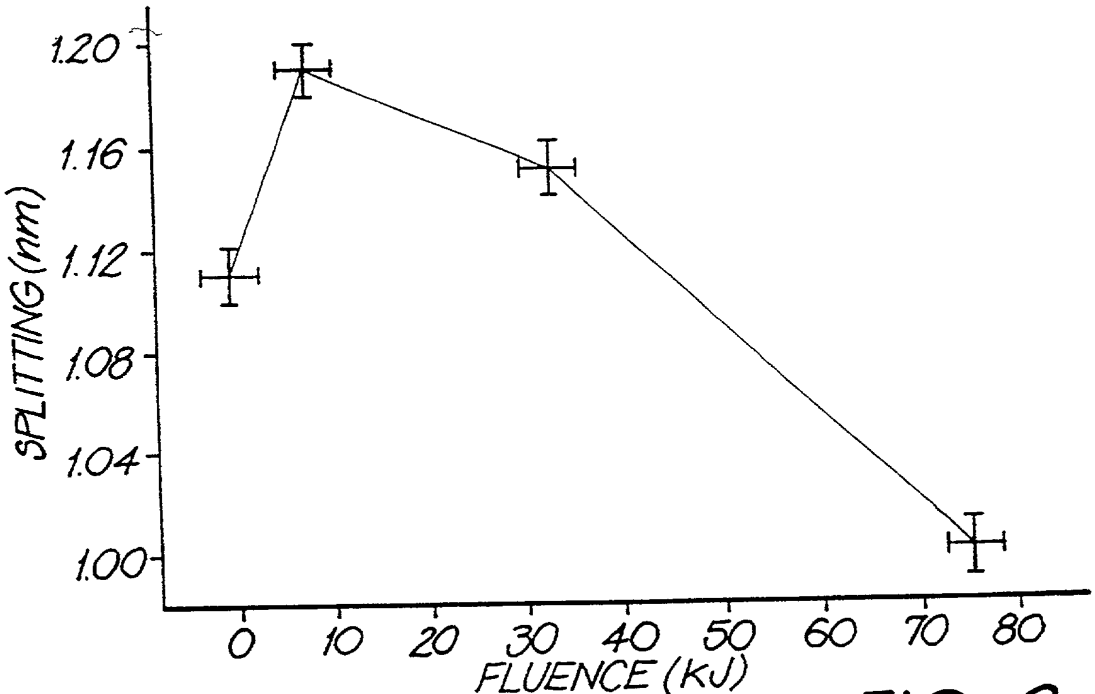
SPLITTING (nm)
1.20
1.16
1.12
1.08
1.04
1.00
0
10
20
30
40
50
60
70
80
FLUENCE (kJ)

FIG. 3

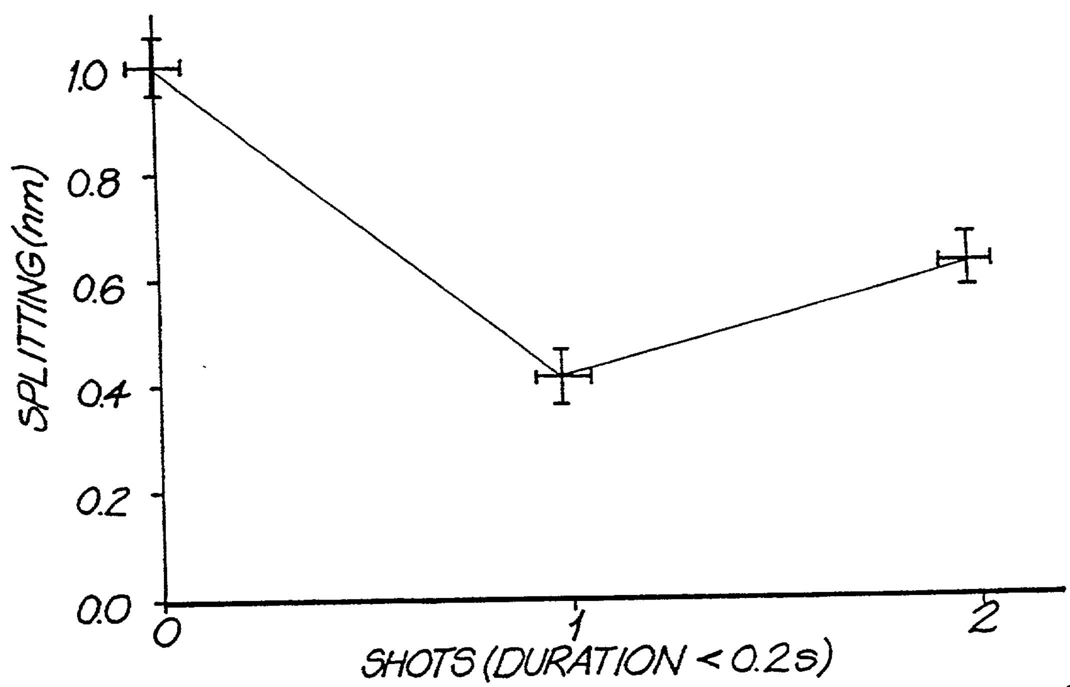
SPLITTING (nm)
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
SHOTS (DURATION < 0.2s)

FIG. 4

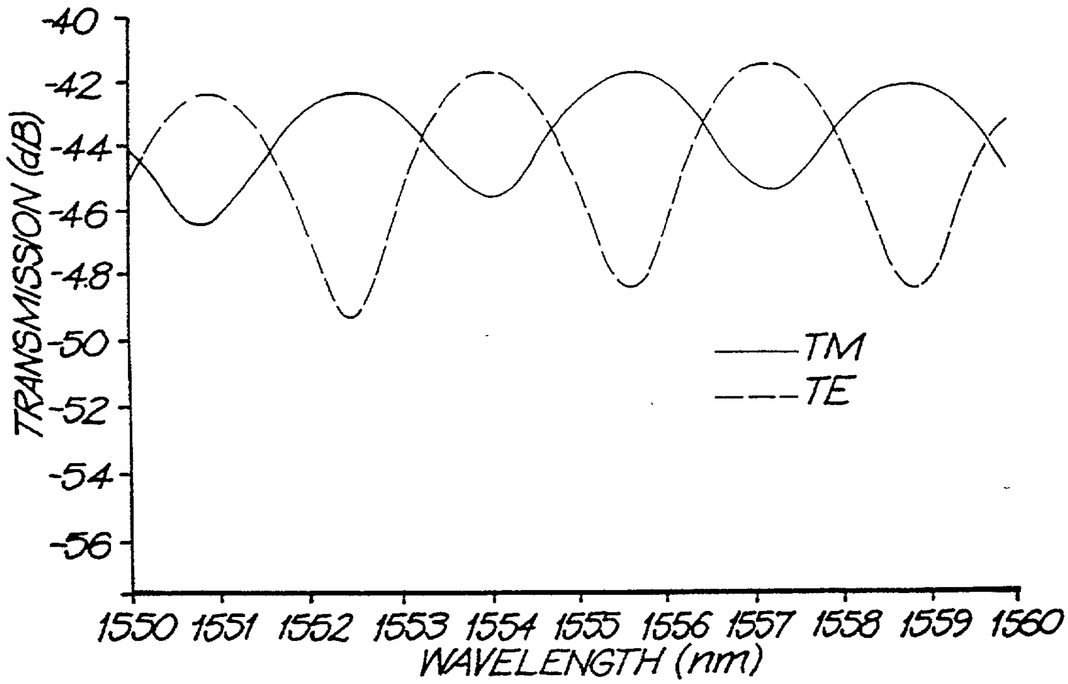
-40
-42
-44
-46
-48
-50
-52
-54
-56
TRANSMISSION (dB)
TM
TE
1550 1551 1552 1553 1554 1555 1556 1557 1558 1559 1560
WAVELENGTH (nm)

FIG. 5

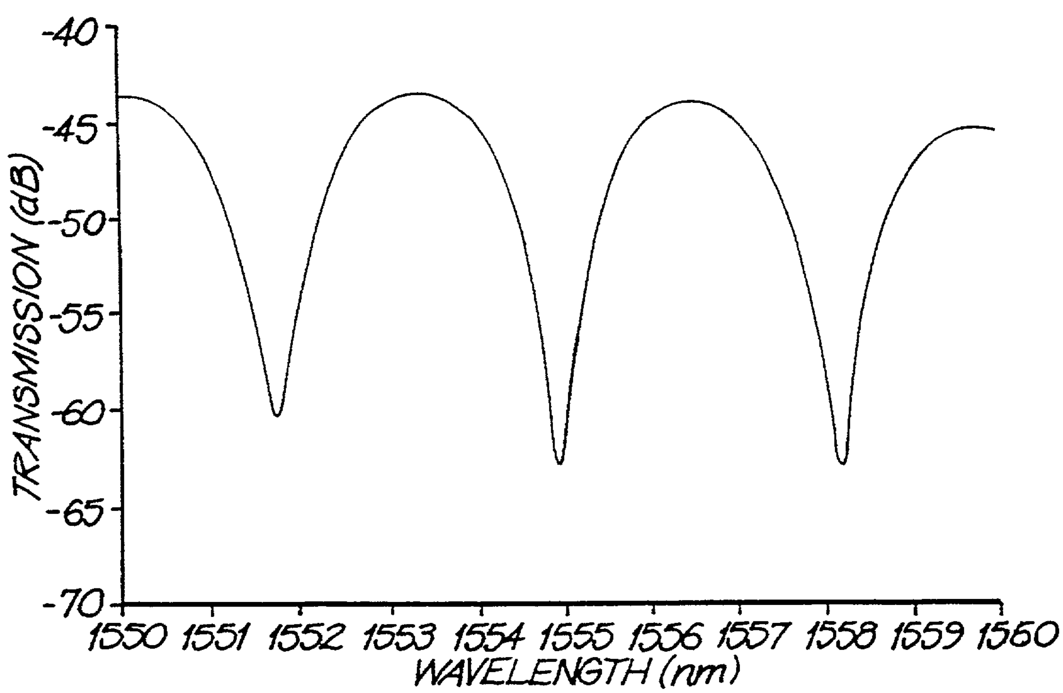
-40
-45
-50
-55
-60
-65
-70
TRANSMISSION (dB)
1550 1551 1552 1553 1554 1555 1556 1557 1558 1559 1560
WAVELENGTH (nm)

FIG. 6

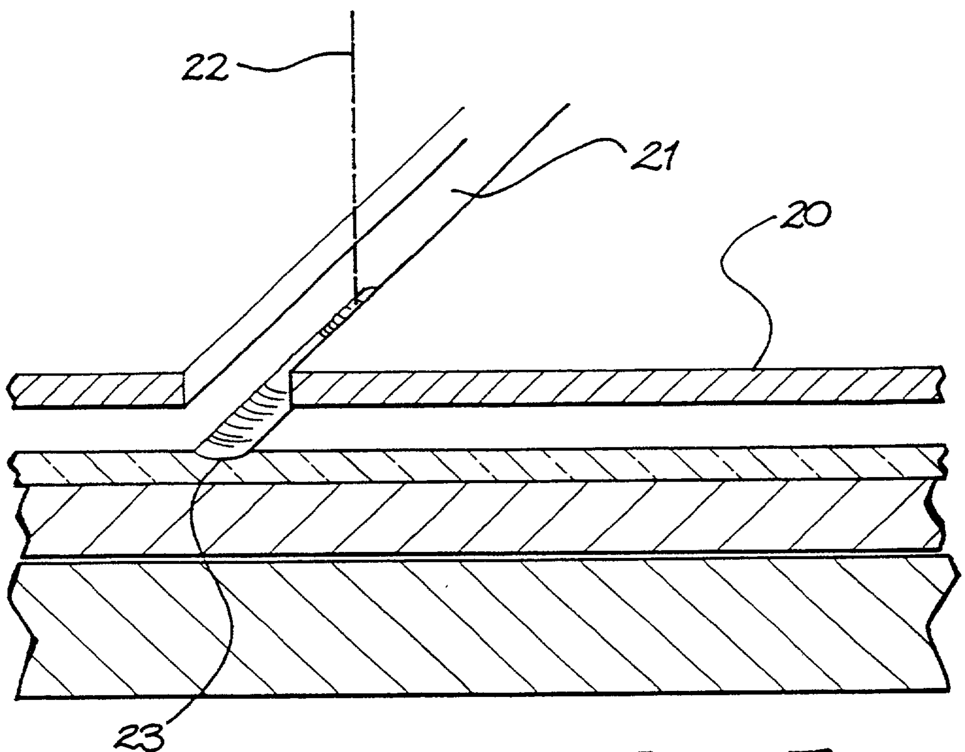

FIG. 7

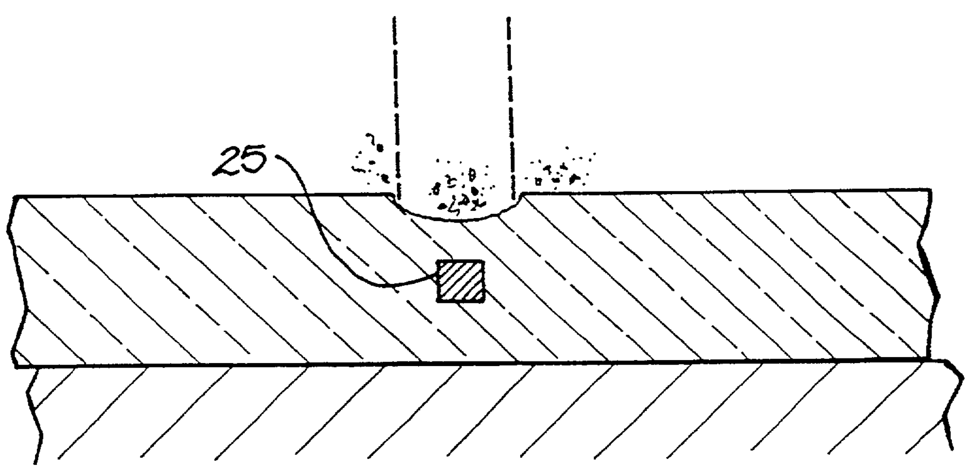

FIG. 8

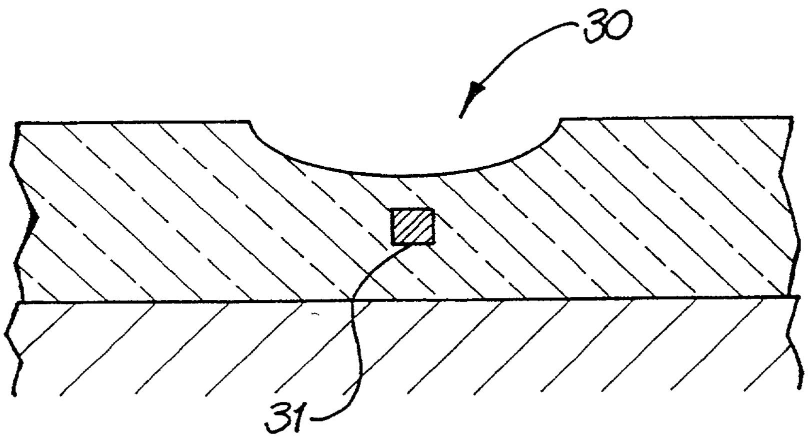

FIG. 9

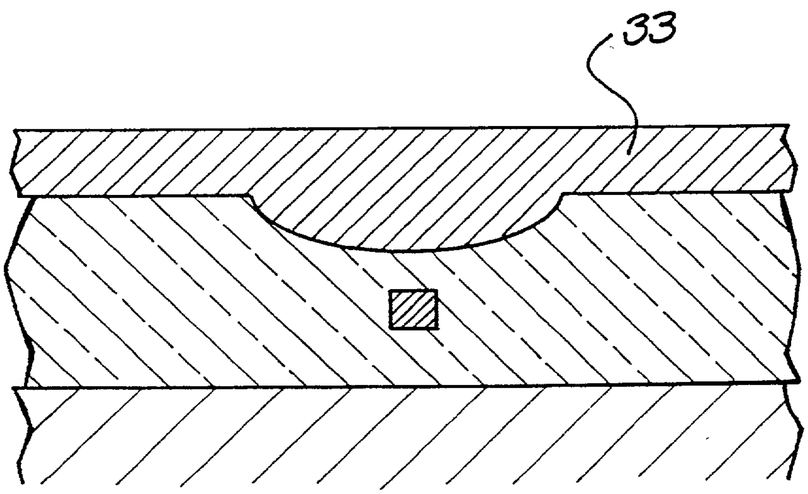

FIG. 10

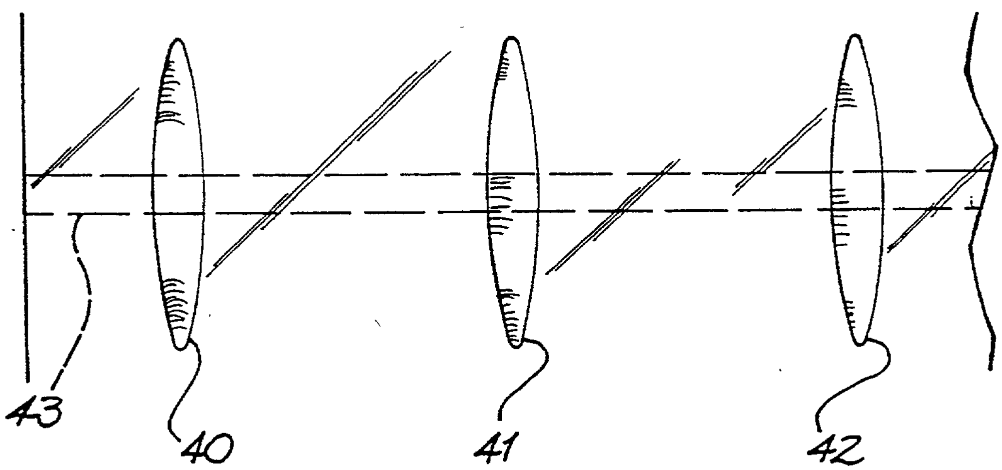

FIG. 11

Rec'd PCT/PTO 04 SEP 2001

PATENT

Docket: CU-2605

COMBINED DECLARATION AND POWER OF ATTORNEY

(ORIGINAL, DESIGN, NATIONAL STAGE OF PCT, SUPPLEMENTAL, DIVISIONAL, CONTINUATION OR CIP)

As a below named inventor, I hereby declare that:

TYPE OF DECLARATION

This declaration is of the following type: *(check one applicable item below)*

original
design

supplemental

Note: *If the Declaration is for an International Application being filed as a divisional, continuation or continuation-in-part application, do not check next item; check appropriate one of last three items.*

X national stage of PCT

Note: *If one of the following 3 items apply, then complete and also attach ADDED PAGES FOR DIVISIONAL, CONTINUATION OR CIP.*

divisional
continuation
continuation-in-part (CIP)

INVENTORSHIP IDENTIFICATION

WARNING: *If the inventors are each not the inventors of all the claims, an explanation of the facts, including the ownership of all the claims at the time the last claimed invention was made, should be submitted.*

My residence, post office address and citizenship are as stated below, next to my name. I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter that is claimed, and for which a patent is sought on the invention entitled:

TITLE OF INVENTION

LASER ABLATION OF WAVEGUIDE STRUCTURES

SPECIFICATION IDENTIFICATION

the specification of which: *(complete (a), (b) or (c))*

(a) is attached hereto.
(b) was filed on as Serial No. or
Express Mail No. *(as Serial No. not yet known)*
and was amended on *(if applicable)*.

Note: Amendments filed after the original papers are deposited with the PTO that contain new matter are not accorded a filing date by being referred to in the Declaration. Accordingly, the amendments involved are those filed with the application papers or, in the case of a supplemental Declaration, are those amendments claiming matter not encompassed in the original statement of invention or claims. See 37 CFR 1.67.

X (c) was described and claimed in PCT International Application No. PCT/AU00/00099 filed on 14 February 2000.

ACKNOWLEDGEMENT OF REVIEW OF PAPERS AND DUTY OF CANDOR

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information, which is material to patentability as defined in 37, Code of Federal Regulations, § 1.56,

(also check the following items, if desired)

and which is material to the examination of this application, namely, information where there is a substantial likelihood that a reasonable Examiner would consider it important in deciding whether to allow the application to issue as a patent, and

in compliance with this duty, there is attached an information disclosure statement, in accordance with 37 CFR 1.98.

PRIORITY CLAIM (35 U.S.C. § 119(a)-(d))

I hereby claim foreign priority benefits under Title 35, United States Code, § 119(a)-(d) of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed.

(complete (d) or (e))

(d) no such applications have been filed.

(e) X such applications have been filed as follows.

Note: *Where item (c) is entered above and the international application which designated the U.S. itself claimed priority check item (e), enter the details below and make the priority claim.*

PRIOR FOREIGN/PCT APPLICATION(S) FILED WITHIN 12 MONTHS (6 MONTHS FOR DESIGN) PRIOR TO THIS APPLICATION AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. § 119(a)-(d)

COUNTRY (OR INDICATE IF PCT	APPLICATION NUMBER	DATE OF FILING (day/month/year)	PRIORITY CLAIMED UNDER 35 USC 119
Australia	PP 8655	12 February 1999	YES X NO
			YES NO

CLAIM FOR BENEFIT OF PRIOR U.S. PROVISIONAL APPLICATION(S) (35 U.S.C. § 119(e))

I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below:

PROVISIONAL APPLICATION NUMBER	FILING DATE

ALL FOREIGN APPLICATION(S), IF ANY, FILED MORE THAN 12 MONTHS (6 MONTHS FOR DESIGN) PRIOR TO THIS U.S. APPLICATION

Note: *If the application filed more than 12 months from the filing date of this application is a PCT filing forming the basis for this application entering the United States as (1) the national stage or (2) a continuation, divisional, or continuation-in-part, then also complete ADDED PAGES TO COMBINED DECLARATION AND POWER OF ATTORNEY FOR DIVISIONAL, CONTINUATION OR CIP APPLICATION for benefit of the prior U.S. or PCT application(s) under 35 U.S.C. § 120.*

POWER OF ATTORNEY

I hereby appoint the following practitioner(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith *(list name and registration number).*

(120)

Thomas F. Peterson, 24790; Richard J. Streit, 25765; Donald P. Reynolds, 26220; W. Dennis Drehkoff, 27193; Vangelis Economou, 32341; Brian W. Hameder, 45613; Valerie Neymeyer-Tynkov, Reg. 46956; Paul B. West, 18947; Joseph H. Handelman, 26179; Peter D. Galloway 27885; John Richards, 31503; Iain C. Baillie, 24090; Richard P. Berg, 28145

Attached, as part of this declaration and power of attorney, is the authorization of the above-named practitioner(s) to accept and follow instructions from my representative(s).

SEND CORRESPONDENCE TO:

Thomas F. Peterson
c/o Ladas & Parry
224 South Michigan Avenue
Suite 1200
Chicago, Illinois 60604

DIRECT TELEPHONE CALLS TO:
(Name and telephone number)

(312) 427-1300

DECLARATION

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

SIGNATURE(S)

Note: *Carefully indicate the family (or last) name, as it should appear on the filing receipt and all other documents.*

1-00

Full name of first joint inventor John CANNING
(Given Name) (Middle Initial or Name) (Family (or Last) Name)

Inventor's signature

Date 17.8.01 **Country of Citizenship** Australia

Residence Carlton NSW, Australia AUX

Post Office Address 10 Francis Street, Carlton NSW 2218, Australia

2-00

Full name of second joint inventor

Mattias ASLUND

(Given Name) (Middle Initial or Name) (Family (or Last) Name)

Inventor's signature

Date 17/8/01 **Country of Citizenship** Sweden

Residence Cronulla NSW, Australia AUX

Post Office Address 167 The Kingsway, Cronulla NSW 2230, Australia

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